Event stratigraphy of the upper Cretaceous to lower Eocene hemipelagic sequences of the Prebetic Zone (SE Spain): Record of the onset of tectonic convergence in a passive continental margin

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Abstract

In the Eastern Prebetic Zone of SE Spain, upper Cretaceous to lower Eocene hemipelagic sequences deposited in the ancient southern passive continental margin of Iberia are well exposed. The long-term stratigraphy of these sequences is punctuated by six regional tectonic events, which induced rapid changes in palaeogeography and regional tectonics. Each event configured a new genetic scenario for sedimentation, which lasted until the next tectonic reorganization and, in turn, controlled the deposition of an *event bounded stratigraphic unit* (EBSU). The ages of these events, determined chronobiostratigraphically, are: intra-Coniacian, late Santonian, "mid" Maastrichtian, latest Maastrichtian earliest Danian, late Thanetian and intra-Ypresian. All the events, but the first, are interpreted here as the result of contractional tectonic pulses, related to changes in intraplate stresses during the onset of African European convergence. Through correlations with both adjacent shallow marine carbonates (Prebetic platform) and basin pelagites (Subbetic), along with other basins of Iberia and North Africa, the long-term evolution of the continental margin is integrated within the geodynamic framework of the western Tethys.

Keywords: Event stratigraphy; Hemipelagites; Late Cretaceous; Palaeocene; Betics; Spain

1. Introduction

Event stratigraphy is an excellent tool for subdividing stratigraphic records and establishing high-resolution correlations between coeval successions of different depositional settings in a sedimentary basin. It is particularly useful: (1) for the analysis of thick, relatively homogeneous, deep marine successions, where sea-level changes are not clearly recorded and biostratigraphic studies are incompatible with high resolution stratigraphy; and (2) for detailed correlations between such homogeneous successions and their correlative shallow marine sequences, in the absence of a well preserved platform-to-basin transition.

These two circumstances occur in most pelagic/hemipelagic carbonate series that broadly developed in

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the western Tethys during latest Mesozoic and earliest Cenozoic times. These series form wide and relatively homogeneous pelagic/hemipelagic units — such as the "scaglia" facies of Italy and the "chalk" sequences of Western Europe — which, despite their utility for hydrocarbon exploration, are difficult to subdivide and analyse. In addition, their correlation with nearby shallow carbonate platforms is usually problematic and limits further understanding of the evolution of sedimentary basins.

The upper Cretaceous and Palaeocene hemipelagic carbonates analyzed in this paper are not exempt from these problems. These carbonates were deposited in the ancient southern continental margin of Iberia — the so-called Betic Margin — and, for years, have been difficult to subdivide and precisely correlate with coeval shallow marine successions, mainly because of the lack of precise elements for time-correlations (e.g., Vera et al., 1982).

In this paper, we report the long-term event stratigraphy of the upper Cretaceous and Palaeocene deposits of the proximal hemipelagic/pelagic settings of the Betic Margin and discuss the relationship between the events identified and the development of the basin, its tectonic history and global events.

2. Geological framework and study area

The Prebetic is a broad Alpine tectonic unit that corresponds to the outer portion of the foreland fold-and-tbrust belt of the Betic Cordillera, in SE Spain. It consists of a para-autochthonous sedimentary cover of Mesozoic–Cenozoic age, which became detached from the Variscan basement along Upper Triassic evaporites during the main orogenic stage, in the Early and Middle Miocene. The sedimentary cover was originally deposited in the southern continental margin of Iberia (Fig. 1), a basin derived from the break-up and divergence of Africa and Europe in the Mesozoic, which during the late Cretaceous–early Cenozoic underwent transition from a passive to a convergent margin (e.g., Martín-Chivelet et al., 2002).

The Prebetic unit includes thick carbonate successions (up to 1000 m) of Late Cretaceous and Early Palaeogene age that were deposited in environments ranging from coastal to bathyal. On the basis of these series and from a palaeogeographical perspective, we differentiate between a north-western area, or *Prebetic Platform*, defined by the dominance of shallow marine carbonates, and a south-eastern region, or *Hemipelagic Prebetic*, characterized by deeper facies (Fig. 1). Unfortunately, the platform-to-basin transition is poorly preserved, since the platform margin was strongly deformed during final compression episodes.

This report focuses on the Hemipelagic Prebetic area, spanning most of the Alicante province and part of the Murcia province in SE Spain (Fig. 1). This zone, with excellent exposures of upper Cretaceous and Palaeogene hemipelagites, occupies a unique palaeogeographical position, between the shallow carbonate settings of the "Prebetic platform" (e.g., Fourcade, 1970; Azema et al., 1979; Martín-Chivelet, 1992) and the deepest pelagic environments of the Subbetic (e.g., García Hernández et al., 1980; Vera, 1986; 1988). The latter constitutes an allochthonous tectonic unit, overthrusting the southernmost portion of the Prebetic. For the purpose of regional comparisons, we also examined the Subbetic Zone near Caravaca de la Cruz, a world-wide reference area for the study of global bioevents (i.e., Cretaceous–Palaeogene — K/P — and Palaeocene–Eocene — P/E — boundaries: Canudo et al., 1991; Molina et al., 1994; Canudo et al., 1995; Molina et al., 1998; Kaiho and Lamolda, 1999; Arz et al., 2000; Molina et al., 2005; Chacón and Martín-Chivelet, 2005a; among others).

3. Methods and data

The stratigraphic analysis of monotonous sedimentary successions, in which relative sea level changes are barely recorded, requires that we de-emphasis "pure" sequence stratigraphic methods and search for alternative criteria to chronostratigraphically subdivide and genetically interpret sedimentary infill at time scales of 10^5–10^6 years. Among these criteria, the recognition and characterization of stratigraphic events (and the stratigraphic rock units they bound) in such sedimentary record appears as a useful tool.

Using this approach to analyse and correlate the late Cretaceous and Palaeocene hemipelagic carbonate successions of the Prebetic, we characterized a series of stratigraphic events that can be traced, at least on a regional scale. These events, and the resultant *event bounded stratigraphic units* (EBSUs) comprise a new regional stratigraphic framework and a sound basis for interregional correlations.

The concept of "event" in the stratigraphic literature is rather different depending on the authors and their scientific disciplines (e.g., Einsele et al., 1991; Walliser, 1996; Einsele, 1998). In the present work, the terms "event" and "event horizon" are used in a wide geological sense. We consider events as rare — but not necessarily exceptional — and rapid — but not strictly instantaneous— processes that occur in (or affect) a region. These incidents can be of different origin and duration and can cause abrupt changes in sedimentation, ecology, biology, geography and accommodation

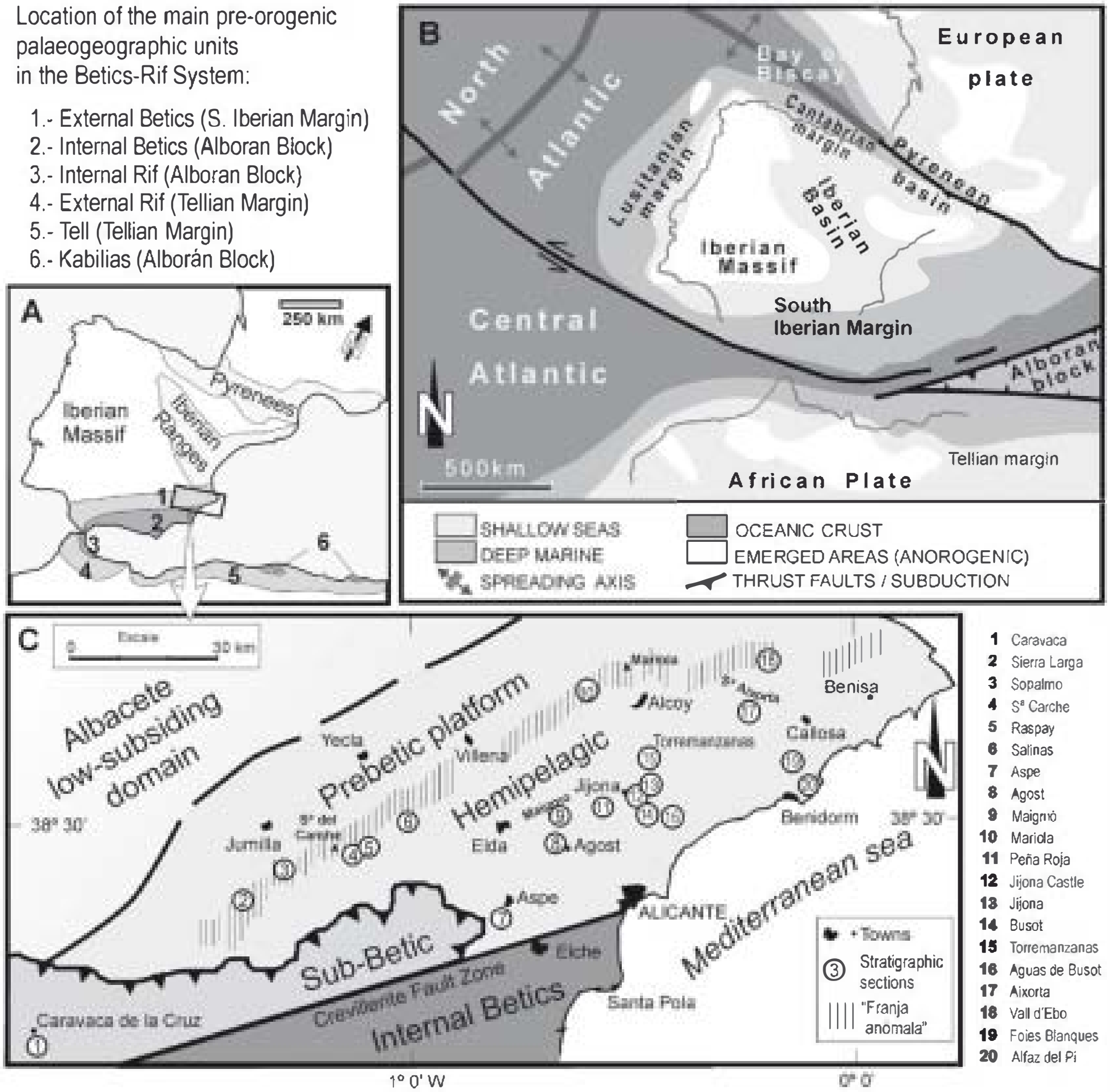

Fig. 1. Geological and palaeogeographical location of the study area. A) Present location in the western Mediterranean of the main Cretaceous–Palaeocene palaeogeographic domains and basins, including the ancient southern continental margin of Iberia. B) Late Cretaceous (late Santonian) palaeogeographic reconstruction of the same area according to Ziegler (1988). C) Location of the study area and main stratigraphic sections in SE Spain cited in this paper. This map shows the main tectonic units and palaeogeographical features mentioned in the text.

patterns. The stratigraphical records of such events are the event horizons, which can be depositional, non-depositional or erosional (e.g., Einsele, 1998). As the response to an event may be different depending on the environment, water-depth, geographic location, etc., event horizons always change laterally. The same event can be recorded at different locations in a basin as a sedimentary bed, as an unconformity, as a hiatal surface, or as a rapid change in the sedimentary facies or fossil assemblages.

An important aspect to consider is that each event not only represents a short time interval during which certain environmental conditions are provisionally altered, but also induces substantial permanent palaeogeographical and basin changes that last until the next event takes place. Thus, each event prepares the scenery for the next EBSU to be generated, and each EBSU constitutes a genetic unit that comprises deposits generated in different, yet coetaneous, sedimentary settings, genetically related by a series of tectonosedimentary and environmental conditions, which prevail until abruptly modified by the following event. These genetic conditions involve, among other aspects, subsidence patterns, palaeogeography, water-depth, and environments.

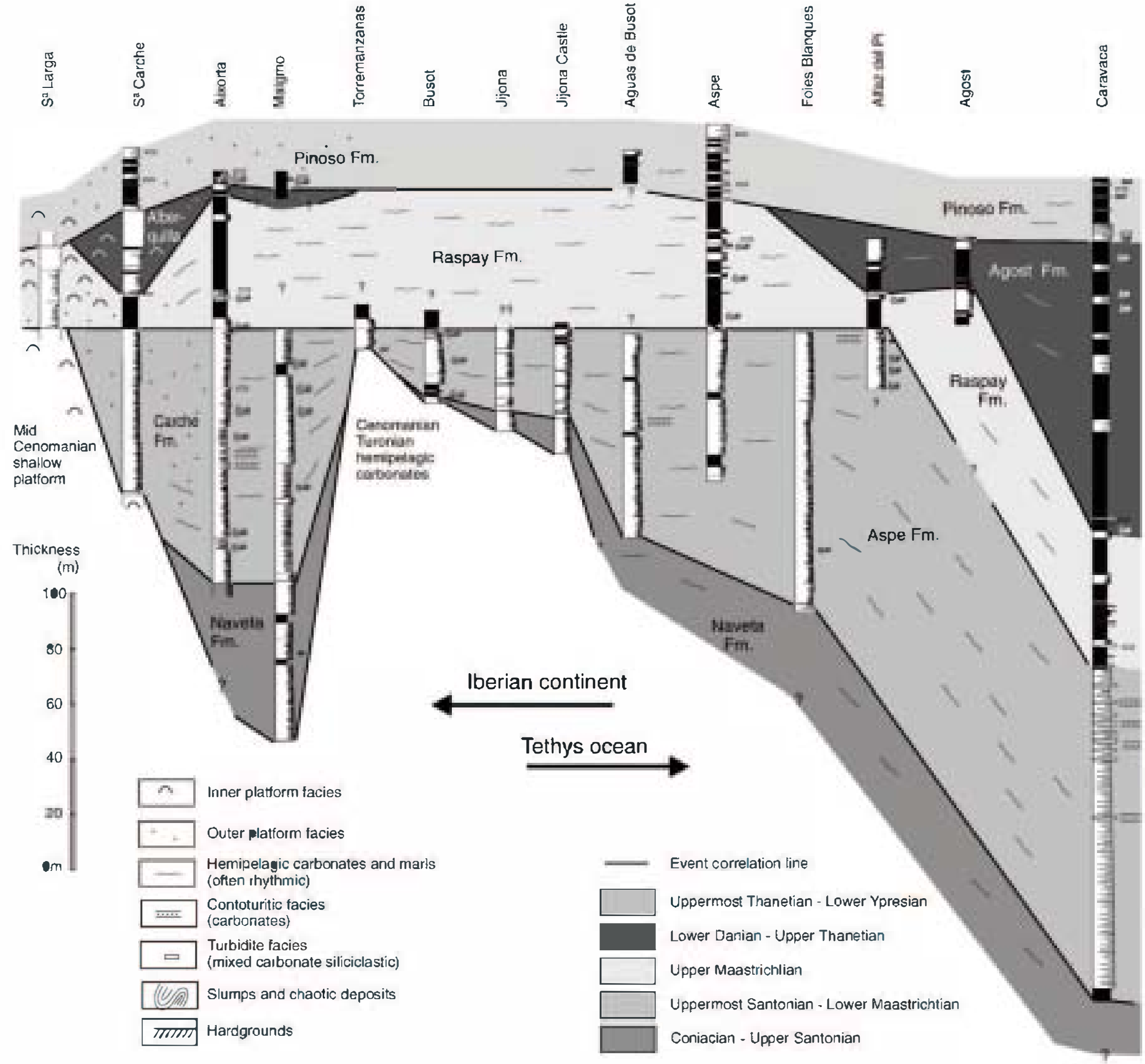

Fig. 2. Correlation panel for the Coniacian to Ypresian interval in the "Hemipelagic Prebetic". The section of Caravaca (Subbetic) has also been included. Note that the horizontal scale is arbitrary, and that logs are arranged according to their palaeogeographic proximity to land.

The results herein presented are based on the study of 20 stratigraphic sections and several local outcrops that were investigated in detail for the Coniacian to Ypresian interval (Fig. 1). Facies analysis permitted the characterization of sedimentary environments and their changes throughout these sections, and biostratigraphic studies, mainly based on the distribution of planktonic foraminifera (detailed in Chacón et al., 2004), have allowed the precise age-dating of the successions. In these studies, six main event horizons were characterized, dated and correlated. The horizons subdivide the upper Coniacian to Ypresian series into five main rock packages or EBSUs. The distributions of event horizons, lithostratigraphic units, biozones and EBSUs are shown in Figs. 2, 3 and 4.

The duration of these EBSUs ranges from less than 3 million years to more than 10. The events occurred much more rapidly and always in time lapses notably shorter than their chronobiostratigraphy is capable of resolving.

4. Event stratigraphy and basin development

In this section, the long-term development of the hemipelagic/pelagic domains of the Prebetic is presented

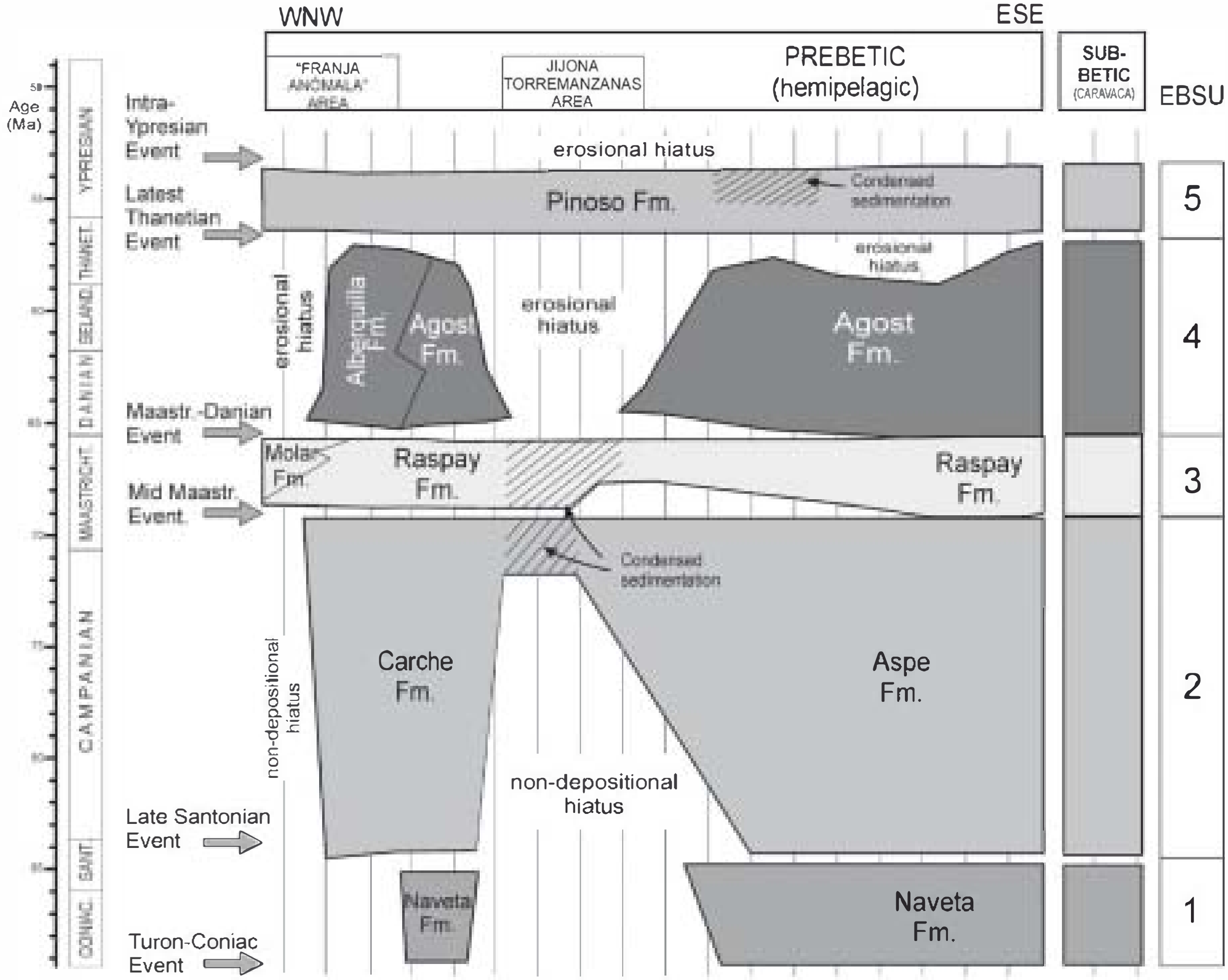

Fig. 3. Chronostratigraphic summary chart for the Coniacian–Ypresian interval showing spatial and temporal distributions of lithostratigraphic units, hiatuses and event bounded units (EBSUs). Time scale after Gradstein et al. (2004).

for the interval late Coniacian to Ypresian. This section is organized according to the six main event horizons identified in the study area and to the sedimentation that took place between each two successive events, recorded in the five event bounded stratigraphic units. All events and units are described in chronological order.

4.1. Pre-Coniacian basin development

In the Betic Margin, the late Albian–mid Cenomanian interval is characterized by a remarkable absence of tectonic activity, with thermal cooling of the lithosphere and eustatic changes being the main factors controlling basin accommodation changes (Martín-Chivelet, 2003). Along with the mid Cretaceous sea level highstand, this situation allowed the spread of shallow marine waters tens of kilometres landwards, giving rise to the widest carbonate platforms known in the area. This episode of relative tectonic quiescence ended however in the mid Cenomanian, which saw the start of a tectonically unstable period continuing until the early–middle Coniacian. Tectonic activity, reported in different areas of the Prebetic (e.g., Hoedemaeker, 1973; De Ruig, 1992; Martín-Chivelet, 1992, 1995, 1996; Chacón, 2002; Chacón and Martín-Chivelet, 2003), provoked a complex scenery of topographic highs and troughs, in response to multi-phase reactivation or the generation of listric faults.

On the Prebetic Platform, listric fault movements caused the development of an ENE–WSW complex trough with shallow marine carbonate sedimentation, bounded by two elevated and emergent areas lacking sedimentation (Martín-Chivelet, 1995). One of these areas, towards the NW, roughly coincides with the so-called *Albacete Domain*, a stable, low subsident, semicratonic zone attached to the continent. The other area, to

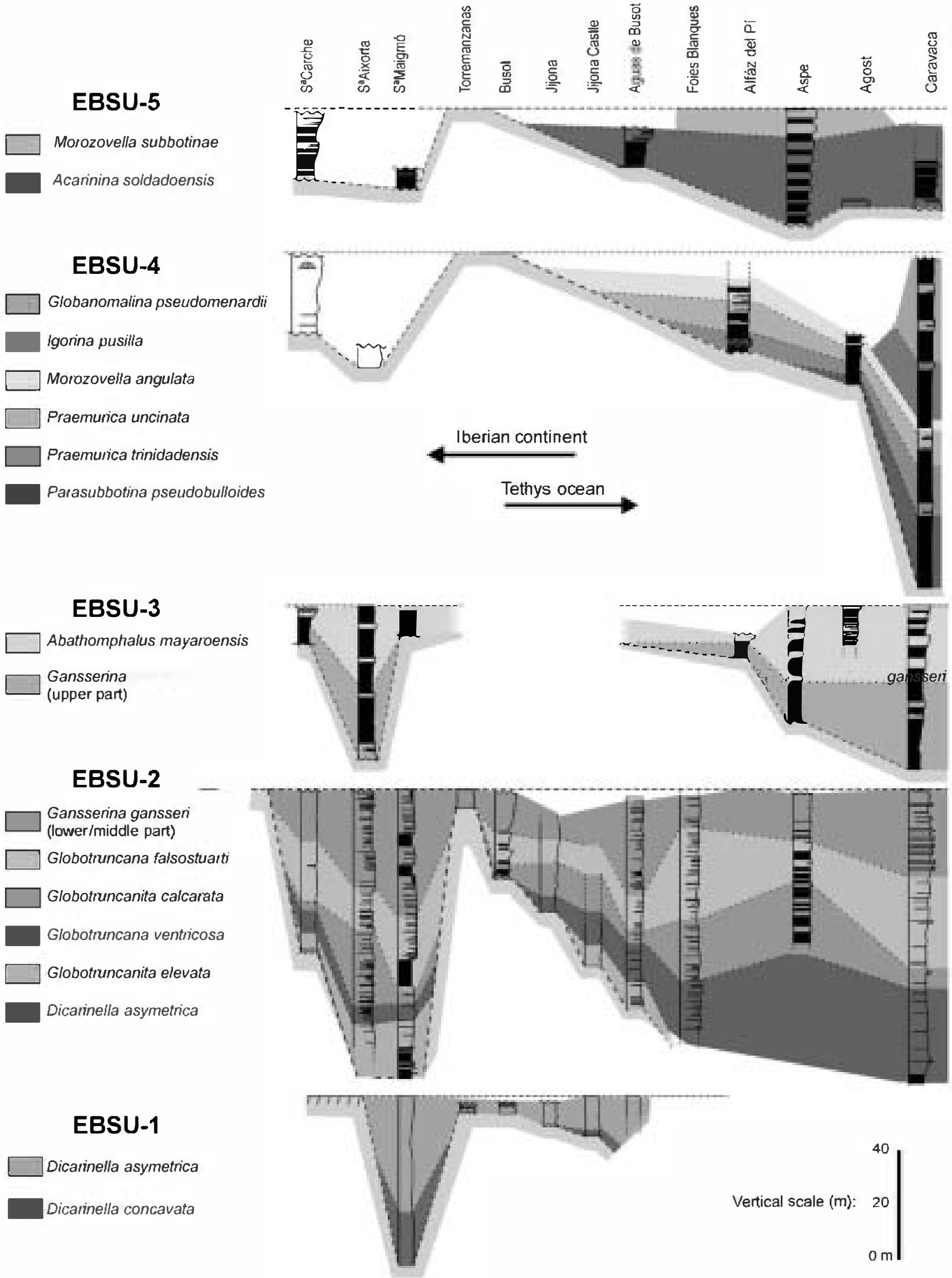

Fig. 4. Biocorrelation panel for each of the five event bounded units differentiated in this paper, showing the distribution of the main biozones of planktonic foraminifera.

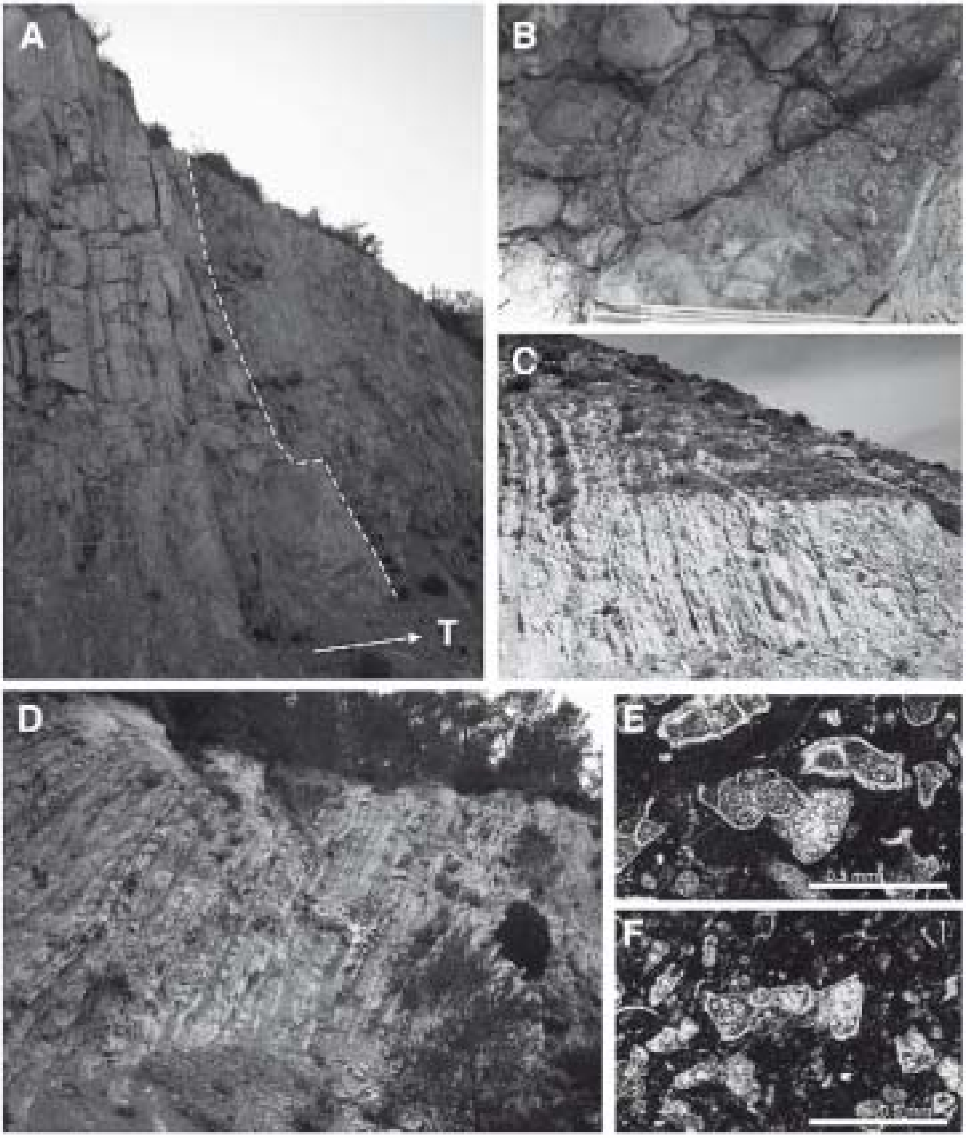

Fig. 5. Field aspects of the Turonian–Coniacian event and EBSU-1. A) Discontinuity (outlined) in the Busot section. White arrow marks the top of the section. B) Bioturbation and micritic lithoclasts included at the base of EBSU-1 after the Turonian–Coniacian event in the Maigmó section. C) Monotonous hemipelagic succession of limestones and marly limestones of EBSU-1 (Naveta Fm) in the Jijona section. D) Part view of EBSU-1 (Naveta Fm) in the Maigmó section. E-F) Diagnostic planktonic foraminifera species in EBSU-1: *Dicarinella concavata* (E) and *Dicarinella asymetrica* (F).

the SE, corresponded to an emergent, narrow and intensely-elongated block, which separates shallow waters from those of the hemipelagic area basinwards (Fig. 1). This area, designated *Franja Anómala* ("Anomalous fringe") by Martínez del Olmo et al. (1982), extended over several hundreds of kilometres along the Prebetic for much of late Cretaceous, and constitutes the northwestern limit of the area considered in this paper.

Basinwards of the Franja Anómala, late Cenomanian to early Coniacian block movements also configured complex geometries of troughs and permanently submerged highs, bounded by listric faults (De Ruig, 1992; Chacón, 2002). Troughs were partially filled by the discontinuous syntectonic deposition of hemipelagic carbonates and marls, with some olistholiths, whilst the highs became characterized by condensed hemipelagic sedimentation and/or hardground development (Chacón, 2002). Among these, the *Torremanzanas High* in the centre of the study area, formed a positive topographic feature during most of the Late Cretaceous and probably the early Palaeogene, separating shallower hemipelagic sediments to the WNW from deeper ones to the ESE (Figs. 2, 3 and 4). In this area, De Ruig (1992) described preserved listric faults that were active during the late Cenomanian–Turonian interval. These faults were sealed by early 'Senonian' deposits, suggesting that fault main activity ceased during latest Turonian or early Coniacian times, although they later underwent several episodes of reactivation.

4.2. Intra-Coniacian event

The end of the main phases of tectonic movements of the late Cenomanian–early Coniacian provoked a stratigraphic event, recorded regionally on a hiatal surface that represents a variable gap. Cenomanian to upper Turonian deposits were overlain by upper Coniacian, Santonian or even younger sediments. This heterochronicity is due to the inherited topography of the previous tectonic movements.

In the sections where minimum hiatuses were found (Maigmó and Jijona Castle sections, see Fig. 1 for location), sedimentation after the event started in the late Coniacian (middle–upper part of the *Dicarinella concavata* Zone) (Fig. 4). In these zones, no well developed hardgrounds were found, but a net increase in bioturbation was observed towards the top of the underlying unit and small lithoclasts of these deposits appeared, incorporated in the basal level of the overlying unit (e.g., Maigmó), indicating sea floor hardening and some erosion and reworking of the lithified sediment prior to the re-start of sedimentation (Fig. 5).

4.3. EBSU-1 (upper Coniacian–upper Santonian p.p.)

This renewed tectonic stability and topography inherited from Cenomanian–Turonian tectonism (in which the Franja Anómala and the Torremanzanas High are the most prominent features), controlled hemipelagic sedimentation in the basin during the late Coniacian to the earlier part of the late Santonian interval. Associated with the previous topography, pronounced changes in sediment thickness occurred and the base of the successions shows significant heterochronicity (Fig. 2). The unit is absent from the Franja Anómala (Carche, Salinas, Mariola sections) and the Torremanzanas High (Torremanzanas section). In the Franja Anómala, there is some evidence of subaerial exposure for this period (Martín-Chivelet, 1992, 1995), whilst in the Torremanzanas High, prominent hardgrounds and condensed sections developed.

Sedimentation in depressed areas is comprised of thin-bedded, nearly pure, fine grained hemipelagic biomicrites (Fig. 5). These limestones constitute fairly monotonous hemipelagic successions within the framework of only one lithostratigraphic unit, designated the Naveta Formation (Chacón and Martín-Chivelet, 2005b) (Fig. 3). The Naveta Fm is late Coniacian to late Santonian in age (it includes the middle-upper part of the *D. concavata* Zone and the *Dicarinella asymetrica* Zone) and mainly consists of white wackestones with abundant calcispheres and planktonic foraminifers.

This sedimentation was endured until the late Santonian, when a new regional tectonic event took place in the basin. The tectonic episode, recorded in all the sedimentary successions, marks the upper boundary of EBSU-1.

4.4. Late Santonian event

During the late Santonian interval, a regional tectonic event affected the basin, substantially modifying the palaeogeography and environmental conditions. Renewed fault movements led to regional subsidence variations and submergence of the topographic high of the Franja Anómala.

This event was recognized in all the sections examined, although its stratigraphic record varies from one to another. In the depressed areas, where sedimentation was more continuous (Maigmó, Caravaca), the event was registered by a transitional zone within the hemipelagic sequences, in which a rapid increase in fine siliciclastics is the most obvious change. In other sections, such as Aixorta, the event is marked by a hiatal surface that is sometimes accompanied by a debris flow bed, reflecting some instability of the sea floor (Fig. 6). In the previously emerged Franja Anómala, the event represented a drastic palaeogeographic change: the area sunk rapidly leading to the development of open platform conditions. The resulting deposits, latest Santonian in age, overlay the palaeoalteration surface developed on mid Cenomanian shallow marine carbonates. In contrast, the Torremanzanas High persisted as a submerged, elevated block, after the tectonic event.

The age of the event is late Santonian and occurred within the *D. asymetrica* Zone (Aixorta, Maigmó). In places where there is discontinuity, the resumption of sedimentation after the event usually varies from latest Santonian (*D. asymetrica* Zone, Carche section) to early Campanian (*Globotruncanita elevata* Zone, Jijona Castle section) (Fig. 4).

4.5. EBSU-2 (uppermost Santonian–lower Maastrichtian)

After the latest Santonian event, sedimentation continued in a hemipelagic setting comparable to that of

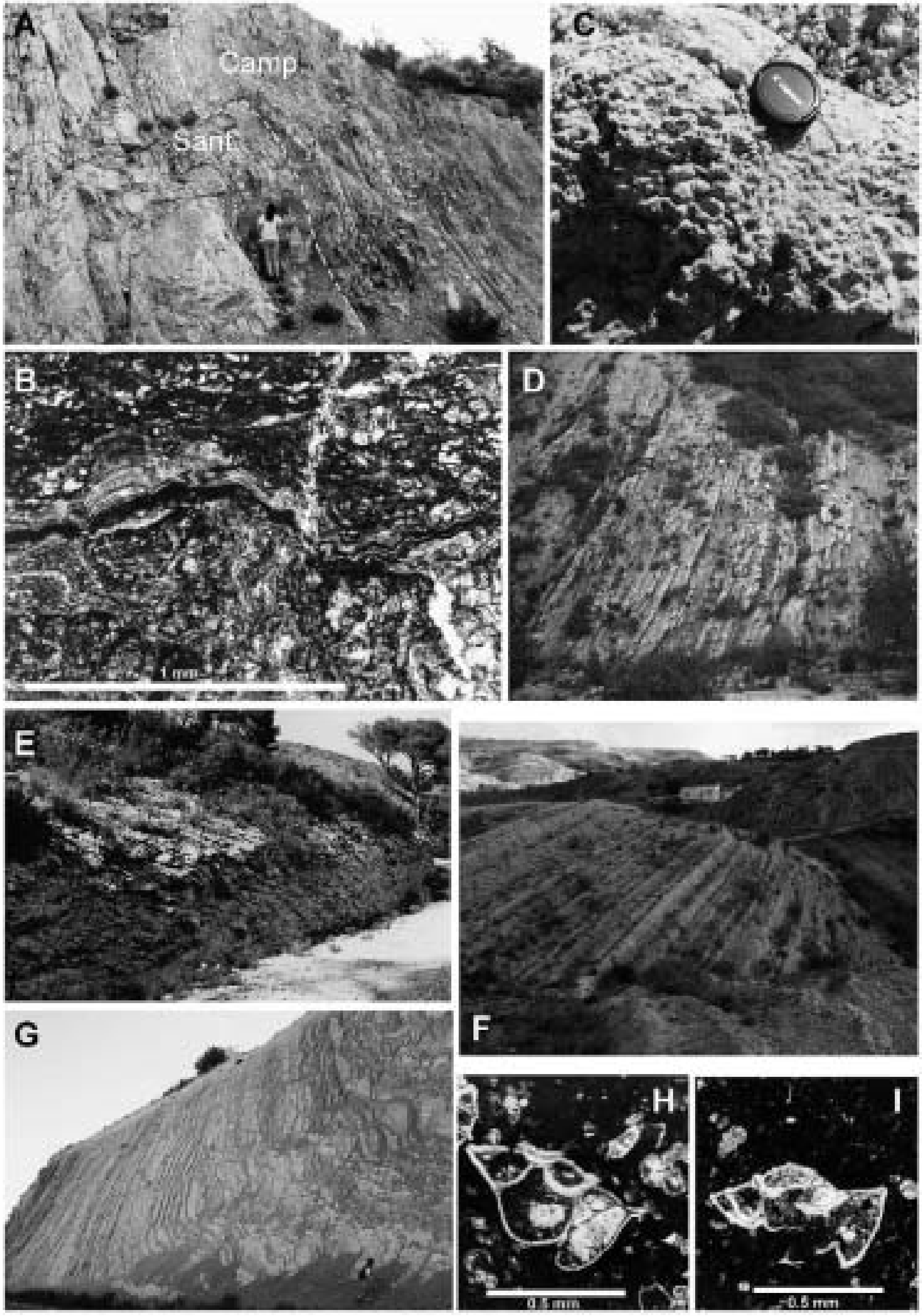

Fig. 6. A) Latest Santonian unconformity (outlined) in Busot, bounding Santonian deposits (top of EBSU-1) and upper Campanian sediments (EBSU- 2). The unconformity is here marked by a hardground, and the associated hiatus includes the latest Santonian to early Campanian interval. B) Microphotograph of the hardground, showing pelagic microstromatolitic laminae. C) Debris flow deposit that marks the latest Santonian event in the Aixorta section. D, E, F and G) Different field aspects of EBSU-2 in (D) the Maigmó section (Carche Fm); (E) Carche section (Carche Fm); (F) Aspe section (Aspe Fm); and (G) Jijona-Torremanzanas area (Aspe Fm). H–I). Diagnostic planktonic foraminifera species in EBSU-2: *Globotruncanita calcarata* (H) and *Globotruncanita elevata* (I).

EBSU-1, but with slightly deeper water-depths and the characteristic feature of including fine siliciclastic deposits. Sedimentation, however, took place in a new basin scenario, in which the previously prominent topographic high of the Franja Anómala had disappeared.

These deposits are framed within EBSU-2, latest Santonian to early Maastrichtian in age. EBSU-2 is represented by two lithostratigraphic units (Fig. 3), roughly age equivalent, but showing substantial differences in facies, stratification and colour, the Carche Fm (Martín-Chivelet, 1994; Chacón and Martín-Chivelet, 2005b) and the Aspe Fm (Chacón and Martín-Chivelet, 2005b).

The Carche Formation crops out in the north-western part of the study area (Carche, Salinas, Mariola, Vall d'Ebo, and Maigmó sections), which palaeogeographically corresponds to shallower hemipelagic settings. It is 90 to 110 m thick and consists of light-coloured, often burrowed, limestones and marly limestones, commonly stratified in poorly-defined, 0.1–0.2 m thick, beds (Fig. 6D, E). These yield abundant planktonic and small benthic foraminifers, inoceramids, echinoids, and some ammonoids. Facies analyses indicate carbonate to mixed hemipelagic settings, corresponding to outer platform environments.

Laterally and basinwards, the Carche Formation grades into the Aspe Formation, deposited in hemipelagic settings notably deeper. The Aspe Fm consists of markedly rhythmic successions with alternations of white, pink and red limestones, marly limestones and marls (Fig. 6F, G). These successions are punctuated by dm-scale beds of fine-grained calcarenites, showing abundant traction structures, which have been interpreted as contourite deposits (Martín-Chivelet et al., 2003). The presence of these tractive deposits is variable, being particularly abundant in the Caravaca area, suggesting a new configuration of ocean currents between Iberia and Africa. This passage constituted the main straits affecting the equatorial system of surface and subsurface currents (Philip and Floquet, 2000).

The Aspe Fm shows considerable lateral changes in thickness (7–75 m), especially in the Jijona-Torremanzanas area, where the unit partly covers the Torremanzanas High (Fig. 2). On this elevated block, highly condensed open-water successions were deposited. These include a succession of intensely mineralized hardgrounds, rich in phosphates and glauconite, often showing fine pelagic stromatolitic laminae.

The age of the Carche Fm is latest Santonian to early Maastrichtian, as determined by planktonic foraminifera (Chacón et al., 2004). The unit comprises the following biozones: *D. asymetrica* (only its uppermost part), *G. elevata*, *Globotruncana ventricosa*, *Globotruncanita calcarata*, *Globotruncana falsostuarti* and *Gansserina gansseri* (only its lower-middle part). All these biozones have been also identified in the Aspe Fm, with the exception of the *D. asymetrica* Zone. The Aspe Fm is considered earliest Campanian–early Maastrichtian in age.

4.6. "Mid" Maastrichtian event

A "mid" Maastrichtian tectonic event marked the end of EBSU-2 deposition. This event abruptly changed the geometry and sedimentary conditions of the basin, and configured the new palaeogeography that was to control the development of EBSU-3. The main changes occurring in the study area were: 1) tectonic movements giving rise to small, low-angle, inverse faults (Aspe section); 2) increased instability producing synsedimentary slumps, olistholiths and debris-flows; and 3) substantially enhanced siliciclastic influx, with marly sedimentation becoming dominant after the event.

The tectonic event is recorded in a regional unconformity. In the north-westernmost area, in the Carche section, this surface is marked by an iron-rich surface with a related minor hiatus. More to the south (Aspe section) (Fig. 7B), the event is recorded in a complex interval, revealing intense synsedimentary tectonism: the development of low-angle, inverse faults, synsedimentary slumps and olistholiths (Chacón and Martín-Chivelet, 2001a). In the Subbetic of Caravaca, a debris-flow bed associated with the discontinuity is recognized (Fig. 7C). In other areas, a minor paraconformity or even conformity, correlative to the described unconformity, may be observed (Alfaz del Pi, Maigmó, Aixorta). In all these outcrops, the event was marked by a rapid rise in the argillaceous content of the facies.

The "mid" Maastrichtian event lasted a short time. The deposits immediately below the event horizon have been dated as early Maastrichtian (middle part of the *G. gansseri* Zone) and those resting over it are earliest late Maastrichtian (uppermost part of the *G. gansseri* Zone, characterized by the presence of *Contusotruncana contusa* and/or *Racemiguembelina fructicosa*) (Chacón and Martín-Chivelet, 2001b, 2003, 2005a).

4.7. EBSU-3 (upper Maastrichtian)

After the tectonic event, sedimentation resumed within a new mixed carbonate-siliciclastic, hemipelagic setting, characterized by an intense influx of fine terrigenous material and by much deeper environments than EBSU-2. To the areas of the Franja Anómala that remained emerged (e.g., Sierra Larga), this event meant the resumption of

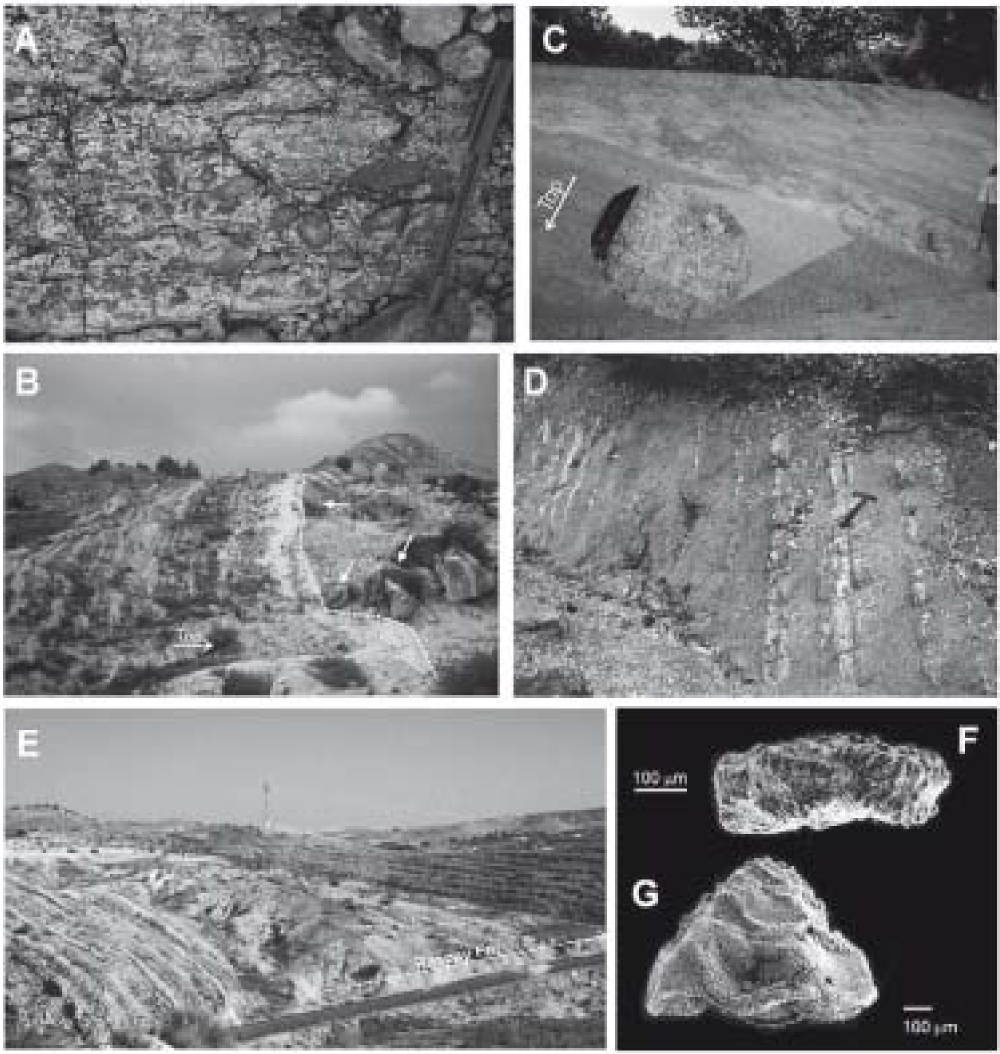

Fig. 7. A, B and C) Field aspects of the "mid" Maastrichtian event. Debris flow beds mark the event in both, Aixorta (A) and Caravaca (C). B) An unconformity (outlined) separates the marly limestones of EBSU-2 from the marls of EBSU-3 in Aspe. The unconformity surface is covered by slumps, and olistholiths (white arrows). D–E) Field aspects of the marls predominant in EBSU-3 (Raspay Fm), in Maigmó (D) and Aspe (E). F–G) SEM images of diagnostic planktonic foraminifera species from EBSU-3: *Abathomphalus mayaroensis* (F) and *Contusotruncana contusa* (G).

sedimentation after more than 25 million years of subaerial exposure. These new conditions controlled the sedimentation of EBSU-3, which lasted until the end of the Maastrichtian.

EBSU-3 essentially consists of marls and marly limestones, greenish to greyish coloured, with some fine limestone intercalations (Fig. 7D, E). These are framed within the Raspay Formation (Martín-Chivelet, 1994; Chacón and Martín-Chivelet, 2005b), which is 7 to 50 m thick and developed over all the study area, including the Torremanzanas High (Fig. 3). The unit contains rich associations of planktonic and benthic foraminifers, ostracods, inoceramids and echinoids, and its deposition took place in a mixed hemipelagic setting, receiving a high fine terrigenous input and sporadic coarse grained turbidite currents, which yielded reworked fragments of shallow water biota, mainly orbitolinids. The rich benthic foraminiferal assemblage (including *Bolivinoides draco draco*; *Cibicidoides velascoensis*; *Coryphostoma incrassata*; *Globorotalites conicus*; *Nuttallinella florealis*; and *Reussella szajnochae*; among others) has enabled an approximation to the water-depth of 200 m or deeper, according to the palaeobathymetry estimations of Van Morkhoven et al. (1986). Sea floor instability is variable spatially, but in some areas (Aspe, Alfaz del Pí) stratification is strongly disturbed by synsedimentary slumps.

The age of EBSU-3 is late to latest Maastrichtian, as it includes the upper part of the *G. gansseri* Zone and the *Abathomphalus mayaroensis* Zone (Fig. 4). Unlike the previous units, the onset of EBSU-3 sedimentation was practically contemporaneous all over the study area, with the exception of the Torremanzanas High, where no sedimentation took place until the latest Maastrichtian. At this point the unit records its minimum thickness (less than 7 m) and consists of a condensed sequence of reddish, nodular, marly limestones to marls.

4.8. Maastrichtian–Danian boundary event

At the end of the Maastrichtian, a new event took place in the basin, indicating the end of EBSU-3 deposition. This new event caused abrupt changes in subsidence, water-depth, biotic assemblages, environments and sedimentary conditions, and prepared the basin for the deposition of EBSU-4 (Danian to late Thanetian interval). The causes of this event were complex owing to a superpositioning of regional tectonics, that induced block movements and differential subsidence, along with the environmental and biological effects of the Cretaceous–Palaeocene (KP) boundary global event.

The record of the event in the basin was found to be different depending on the area. Close to land (Carche, Aixorta), the rate of hemipelagic sedimentation rapidly decreased until ceasing at the end of the Maastrichtian. As a result, an intensely burrowed, bored and mineralized hardground formed (Fig. 8A, B), which eventually became colonized by epibenthonic gastropods and brachiopods. On this surface, open marine, phosphate stromatolites developed (Chacón and Martín Chivelet, 1999; Chacón, 2002). Sedimentation in these areas did not restart until the early (but not earliest) Danian (Carche, Aixorta) or much later, as far as the Thanetian.

Basinwards, the record of the event does not reflect the development of a sedimentary discontinuity. This is the case of the sections of Agost and Caravaca, where the Maastrichtian–Danian transition has a very complete record. Owing to their completeness and the excellent exposure, these sections have become world references for the Cretaceous/Palaeogene boundary (Canudo et al., 1991, Molina et al., 1996, 1998, 2005, among others).

Regionally, the Maastrichtian–Danian event marked the intense reorganization of sedimentary environments. After the event, the north-westernmost areas recorded a decrease in water-depth, and carbonate outer to inner shallow platforms developed over the hemipelagic deposits of the Raspay Fm basinwards. On the contrary, in the southeastern sectors the water-depth rapidly rose and mixed hemipelagic sedimentation continued, although turbidite currents became more abundant.

The regional event took place between the end of the Maastrichtian and the beginning of the Danian. The Maastrichtian–Danian horizon separates the *A. mayaroensis* Zone bearing deposits from sediments that include the *G. cretacea* + *P. longiapertura* Zone (Canudo et al., 1991; Pardo et al., 1996; Molina et al., 1996; Chacón, 2002).

4.9. EBSU-4 (lower Danian–upper Thanetian)

EBSU-4 was deposited under the new environmental and palaeogeographical conditions generated during the Maastrichtian–Danian event, which prevailed until the late Thanetian. We should mention that the sedimentary record of this unit is quite incomplete over most of the study area, and that the interpretations herein presented are limited by the scarcity of outcrops of this age.

The previous event probably determined the generation of a submerged topography, with profound bathymetric differences. Water-depths ranged from very shallow, with the development of reef carbonates in the Carche section, to bathyal in the southernmost areas (Caravaca, Agost). Topographic highs possibly developed in some areas, as suggested by the hardgrounds and strongly condensed sections that formed in the Aixorta area.

EBSU 4 is represented by two lithostratigraphic units: the Alberquilla Fm and Agost Fm (Chacón, 2002; Chacón and Martín-Chivelet, 2005b). Both units are age equivalent, although no lateral intermediate facies were observed between them (Figs. 2 and 3).

The Alberquilla Fm crops out only in the north westernmost zones of the analyzed area, that would palaeogeographically correspond to the shallowest areas, nearer the emerged lands. It is 30 m thick and is formed in its lower part by white to beige, thinly stratified, fine bioclastic, wackestones, rich in rounded planktonic foraminifera, some microbenthic foraminifera, ostracods and fragments of echinoids (Fig. 8D). Upwards, these limestones grade into white, coarser wackestones to grainstones, with abundant large benthic foraminifera, remains of red algae, echinids, bryozoans and bivalves, and massive reefal framestones, with colonial corals and red algae. The vertical succession of facies reveals a rapid transition from proximal outer platform environments to an inner platform, reefal/parareefal setting.

The age estimation of the Alberquilla Fm is mainly based on large benthic foraminifera, which are abundant in its middle and upper parts (Fig. 8F–G). Three Shallow Benthic Zones (SBZ) — 2, 3 and 4 (as defined by Serra-Kiel et al., 1998) — were recognized here.

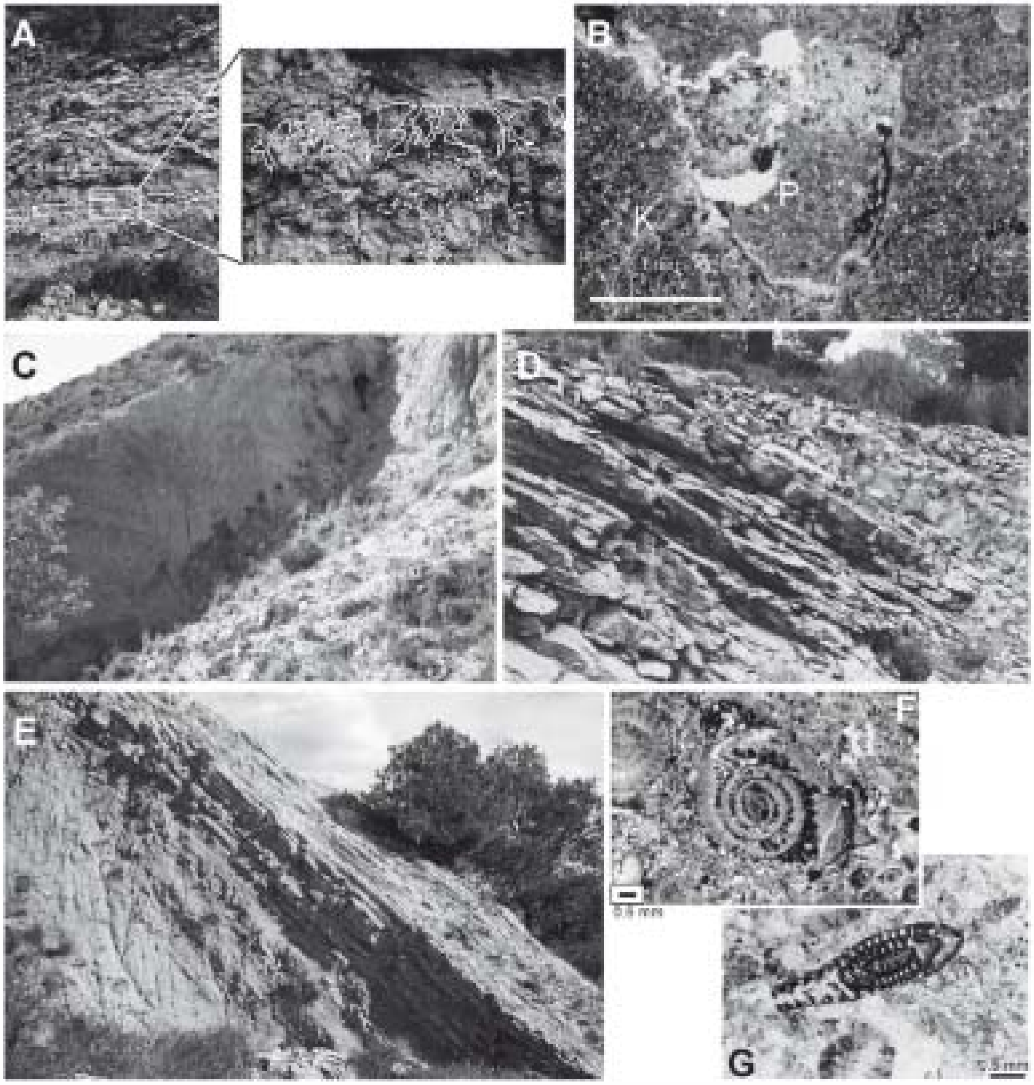

Fig. 8. A) Field aspect of the Maastrichtian-Danian hardground in Sierra del Carche (Carche section) separating the top of EBSU-3 (Raspay Fm) from the limestones of EBSU-4 (Alberquilla Fm). Note the large *Thalassinoides* burrows at the top of EBSU-3. B) Microphotograph of a thin section of the same hardground, showing micro stromatolitic lamination, enriched in phosphates. C, D and E) Field aspects of EBSU-4 in (C) the Agost section (Agost Fm); (D) Carche section (Alberquilla Fm); and (E) Alfaz del Pi section (Agost Fm). F–G) Microscopy images of diagnostic large benthic foraminifera in EBSU-4 (Alberquilla Fm). F) *Nummulites catari*. G) *Hottingerina lukasi*.

According to Serra-Kiel et al. (1998), SBZ 2 is Selandian in age, SBZ 3 is late Selandian to early Thanetian, and SBZ 4 is late Thanetian. The lowermost part of the unit, containing very few large benthic foraminifera, was dated by means of planktonic foraminifera. According to these fossils, the age of the base is early (but not basal) Danian. The unit rests unconformably on the hardground developed at the top of the Raspay Fm.

The Agost Fm, which outcrops in the central and southern areas, averages 15 m thick and mainly consists of red to green marls (Fig. 8C) rich in planktonic and small benthic foraminifera, ostracods and echinoid remains. The Fm also shows fine intercalations of greenish to greyish marly wackestones, particularly in its lower and upper part (Fig. 8E). These materials were deposited in hemipelagic environments receiving high amounts of clays. Based on the rich benthic foraminifer assemblage (including *Bulimina trinitatensis* Cushman and Jarvis, 1928; *C. velascoensis* Cushman, 1925; *Gyroidinoides globosus* Hagenow, 1842 and *Nuttallides truempyi* Nuttall, 1930, among others), a bathyal water-depth deeper than 500 m was calculated for these deposits (Agost, Caravaca), according to the estimates of Berggren and Aubert (1983) and Van Morkhoven et al. (1986). These environments, dominated by low energy settings, suffered sporadic turbidity currents (represented by finely laminated, sandy packstones, mainly in the lower part of the unit) or debris flows (Alfaz del Pi).

The oldest deposits of the Agost Fm are earliest Danian in age. Age dating is based on the most complete sections (Agost and Caravaca), where the first biozone of planktonic foraminifers of the Palaeocene has been identified (e.g.: Canudo et al., 1991; Pardo et al., 1996; Molina et al., 1996, 2005). The top of the unit is intensely diachronous given it is usually capped by an erosive surface. In Caravaca, where this erosive surface is absent, a *Globanomalina pseudomenardii* Zone identified at the top of the unit (Pujalte et al., 1994) indicates a Thanetian age. In the Aixorta region, the deposits corresponding to this time-interval are represented by a condensed sequence, for which depositional rates lower than 0.5 mm/1000 years were calculated. Bored hardgrounds and open marine stromatolitic crusts with abundant entrapped planktonic foraminifera are the most typical features of this sequence.

4.10. Late Thanetian event

In the late Thanetian, a regional tectonic episode once again caused rapid changes in basin geometry and prepared the new tectonosedimentary setting in which the deposition of EBSU-5 would take place. This event, marked by an unconformity in the whole area, defines a major regional change in the sedimentary conditions. These started to be controlled by turbidity currents, which affected most of the area examined.

The event is recorded in the Carche section by a highly burrowed surface at the top of the Alberquilla Fm. This surface marked the end of the development of the reefal complex and the onset of mixed sedimentation of marls and turbidites (Pinoso Fm, see below). In the Aixorta zone, the event is recorded by the generation of an olistolithic unit, which includes large slumps and boulders of latest Cretaceous–Palaeocene age (Fig. 9A, B). In other areas, like Maigmó and Aspe, the event implied intense erosion, which eliminated part or all of the Agost Fm (Palaeocene) and even part of the Raspay Fm (Upper Maastrichtian), before the deposition of EBSU-5 had started (Fig. 3). Basinwards in Caravaca, no substantial erosion occurred, and the event is marked by a rapid increase in the influx of turbidites.

The age of the event is herein considered as late Thanetian. The youngest deposits below the unconformity found in Caravaca, are late Thanetian (*G. pseudomenardii* Zone *sensu* Pujalte et al., 1994, a zone equivalent to P4a and P4b in Berggren and Norris, 1997), whilst the deposits above it are early Ilerdian (the term Ilerdian is used here in the sense of Hottinger and Schaub, 1960 and Orue-Etxebarría et al., 2001). In the Carche section, these deposits correspond to the Shallow Benthic Zone 5 (*sensu* Serra-Kiel et al., 1998) and, in the rest of the study area, to the *Acarininasoldadoensis* Zone (following the biozonation by Pujalte et al., 1994, a zone equivalent to zones P4c and P5 in Berggren and Norris, 1997).

4.11. EBSU-5 (uppermost Thanetian to lower Ypresian)

After the late Thanetian event, sedimentation in most of the area became dominated by outer platform to hemipelagic conditions, strongly influenced by turbidite processes. The result is a heterolithic rock unit of variable thickness (7–30 m), the so-called Pinoso Formation (Chacón and Martín-Chivelet, 2005b), formed by green to ochre marls alternating with ochre, often laminated, sandy packstones to grainstones of turbiditic origin (Fig. 9C, D).

These marls yield rich assemblages of planktonic and benthic foraminifera, some ostracods and echinoid remains, whilst the sandy limestones show considerable mixing with faunal debris. These mixtures include remnants of shallow and deeper biota (fragments of echinids, red algae, bryozoans and *Distichoplax biserialis* (*incertae sedis*), an abundance of large benthic foraminifera, some small benthic foraminifera, ostracods and scarce planktonic foraminifera) that show different degrees of sedimentary reworking (Fig. 9E, F).

The age of EBSU 5 is latest Thanetian to early Ypresian (i.e., middle Ilerdian in the sense of Hottinger and Schaub, 1960; Orue-Etxebarría et al., 2001), based on the study of non-reworked, large benthic foraminifera in the Carche section. These foraminifers led to the identification of SBZ 5 (*sensu* Serra-Kiel et al., 1998; Chacón, 2002) as well as planktonic foraminifera from other sections (Aspe, Caravaca), characterising the *A. soldadoensis* Zone and the lower part of the *Morozovella subbotinae* Zone (equivalent to P6 in Berggren and Norris, 1997).

Although EBSU-5 reflects substantial regional homogenisation of the depositional conditions, in some basinward areas (Aguas de Busot), sedimentation is represented by open marine, red coloured, intensely burrowed, condensed carbonate hemipelagic deposits formed at bathyal depths (Chacón, 2002).

4.12. Intra-Ypresian event

Within the Ypresian, the last of the main tectonic episodes took place, leading to the re-organization of

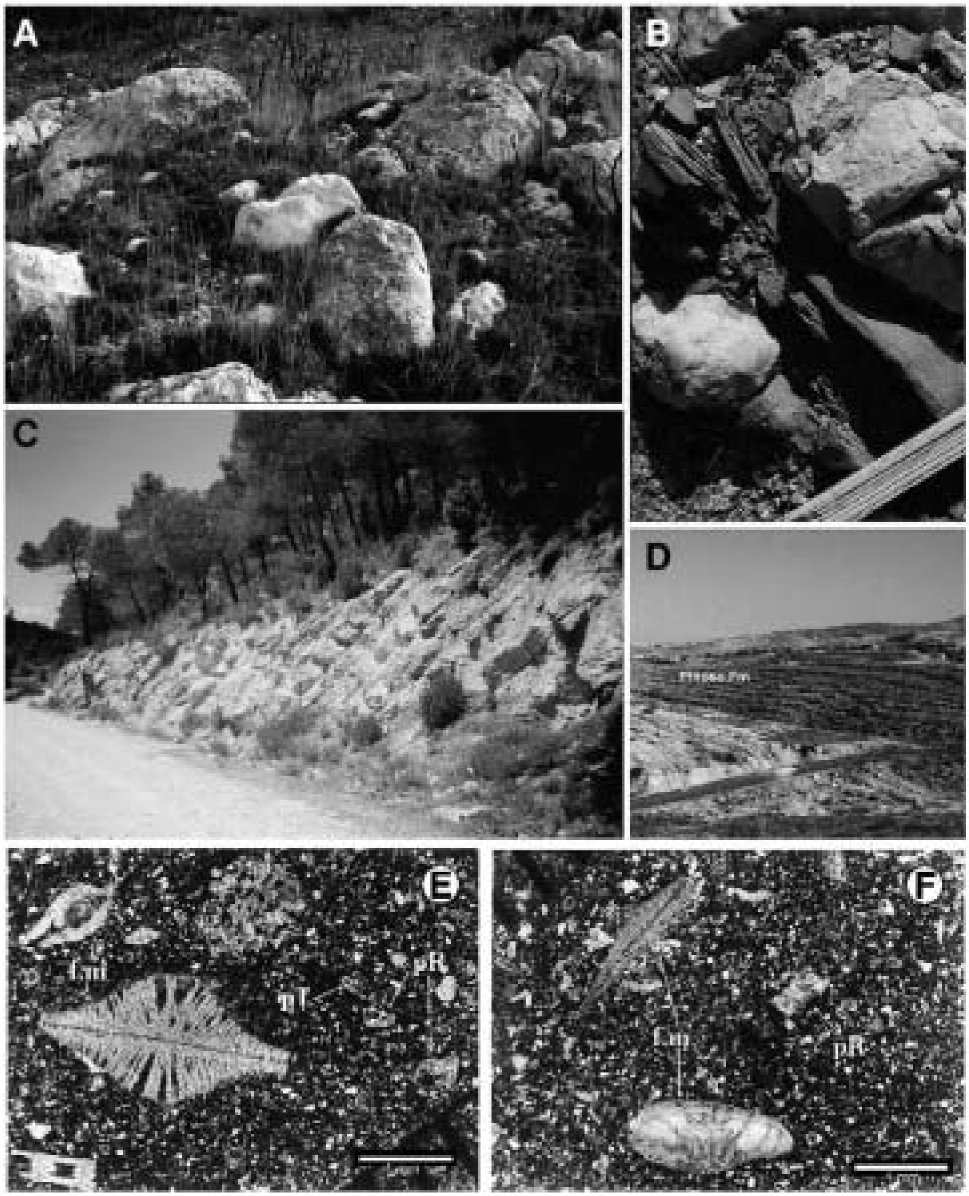

Fig. 9. A) Field aspect of the latest Thanetian event in the Aixorta section, marked by chaotic deposits that include large boulders from the latest Cretaceous limestones (sometimes showing the development of a latest Maastrichtian–Palaeocene hardground). B) Detail of the chaotic bed, showing limestone boulders of latest Cretaceous age embedded in and mixed with late Thanetian dark calcarenites, rich in siliciclastics. C and D) Field views of EBSU-5 (Pinoso Fm) in Sierra del Carche (C) and Aspe (D). E and F) Two aspects of microfacies of EBSU-5 showing a noticeable mixture of remains of faunas from different environments and ages. Key: f.m.: large benthic foraminifera; p.T.: Tertiary planktonic foraminifera; p.R.: Cretaceous planktonic foraminifera (reworked).

sedimentary environments. This meant a change in the sedimentary conditions, although they continued to be relatively homogeneous across the whole area. This event marked the end of EBSU-5 deposition and is recorded by a regional unconformity.

In the north-westernmost area (Carche), the marls and sandy limestones of the Pinoso Fm are limited at the top by an erosive surface, over which green marls, very rich in planktonic and micro-benthic foraminifera, bivalves and fragments of echinids, unconformably rest. In the Maigmó area, sedimentation after the tectonic event is also represented by green marls but, in this area, marls include many thick intercalations of limestones and marly limestones, showing numerous slump structures and some calcarenite and laminated limestone beds of turbiditic origin, very rich in macro-benthic foraminifers.

In the Jijona-Torremanzanas area, the Raspay Fm Maastrichtian deposits are directly covered by Eocene beige to green marls, yielding a rich association of planktonic and micro-benthic foraminifers. Towards the top, these marls alternate with increasingly more numerous and thicker beige marly limestones beds, with abundant nummulitids and miliolids.

We know the event took place within the Ypresian, since the youngest deposits below the unconformity, found in Aspe, are early Ypresian (*M. subbotinae* Zone; P6a Zone of Berggren and Norris, 1997), and the oldest deposits resting over the unconformity have been dated as latest Ypresian (P9 Zone of planktonic foraminifera described by Berggren and Norris, 1997).

5. Factors controlling stratigraphic units and regional events

The events and genetic units (EBSUs) described in the previous section outline the development of the hemipelagic settings of the ancient southern continental margin of Iberia during the end of the Mesozoic and start of the Cenozoic, i.e., the time interval in which this basin changed from a passive continental margin to a convergent one. In this section, the origins of these events and the sedimentary patterns marked by the EBSUs are discussed in the evolutionary framework of the sedimentary basin and the Iberian plate (Fig. 10).

During mid Cretaceous times, Iberia formed a triangle-shaped microplate between Africa and Europe. This microplate was bounded by: the Bay of Biscay's sea-floor spreading axis and its continuation into the North Pyrenean Fault Zone to the north; by the North Atlantic sea-floor spreading axis to the west; and by the Azores and Alboran Facture Zones to the south and southeast (Fig. 1) (e.g., Ziegler, 1988). Southeastwards from this last boundary and partly detached from Africa, was the tectonically mobile, continental block of Alboran-Kabilias. This block was to be crucial in the subsequent evolution of the Betic margin, and part of it today comprises the Internal Zone of the Betic Chain.

The continental part of Iberia was then surrounded by the Pyrenean and Basque-Cantabrian basins to the north, the Lusitanian passive margin to the west and the South Iberian continental (or Betic) margin to the south-southeast. This last margin was the outcome of the break-up and oblique divergence of Africa and Iberia during the whole Mesozoic, with two main extensional phases during early Jurassic and early Cretaceous times (García Hernández et al., 1980; Ziegler, 1988; Vera, 1988, 2001; Vilas et al., 2001). Following the second extensional phase, the basin reached its maximum extension. This occurred during a period of thermal subsidence in the mid Cretaceous (Martín-Chivelet, 1996). After this, the basin entered a complex evolutionary process that precluded its transformation into a convergent margin (e.g., Martín-Chivelet, 1996; Martín-Chivelet et al., 2002). This process was the response to convergence between Africa and Eurasia, which culminated in the Miocene with the head-on continental collision between Africa and Iberia and the formation of the Betic–Rif orogenic belt (e.g., Ziegler, 1988; Dewey et al., 1989).

The sedimentary sequences examined here began their development after a period of regional tectonic activity, which took place in the late Cenomanian and Turonian. Tectonism gave rise to new listric faults (or reactivated pre-existing ones) in the Betic margin and induced abrupt topographic changes in the basin, all related to changes in the intraplate stresses of Iberia (De Ruig, 1992; Martín-Chivelet, 1992, 1996; Martín-Chivelet et al., 2002). At that time, Iberia moved independently, rotating counter-clockwise relative to Europe in response to sinistral, transtensional, movements occurring between Africa and Europe (e.g., Savostin et al., 1986; Ziegler, 1988), and seafloor spreading took place along the axes established from Aptian times in the Bay of Biscay and the North Atlantic (Fig. 10). During the middle Cenomanian to late Turonian interval, the Bay of Biscay ocean axis spreading rate increased, determining an extended, multiphase rise in subsidence at the Basque-Cantabrian margin (e.g., Gräfe, 1994, 2005), and generalized tilting of the Iberian continental massif towards the northwest (e.g., García et al., 1985; Floquet, 1991; Martín-Chivelet and Giménez, 1993; Alonso et al., 1993; Wallrabe-Adams et al., 2005). Simultaneously, at the southern plate boundary (Alboran Fault Zone), possibly the first transpressional–compressional movements occurred, as revealed by the short phase of low temperature–high pressure metamorphism that took place in the Alboran-Kabilias block around 91 Ma (De Jong, 1990; Kuhnt and Obert, 1991; Puga et al., 2002).

In the study area, the end of the phase of tectonic activity corresponds to the Coniacian, coinciding with the "88.5 Ma extensional tectonic event" described for the Prebetic platform by Martín-Chivelet (1996). Upper Coniacian and Santonian deposits, under conditions of relative tectonic quiescence, sealed the former listric faults, and covered all the area, except for the inherited topographic highs. These aspects, along with the homogeneity of facies, suggest substantial relaxation of previous tectonic stresses.

The late Coniacian to early late Santonian was, in fact, an interval of moderate but generalized subsidence in nearly all the basins of Iberia (Fig. 10) (e.g., Floquet,

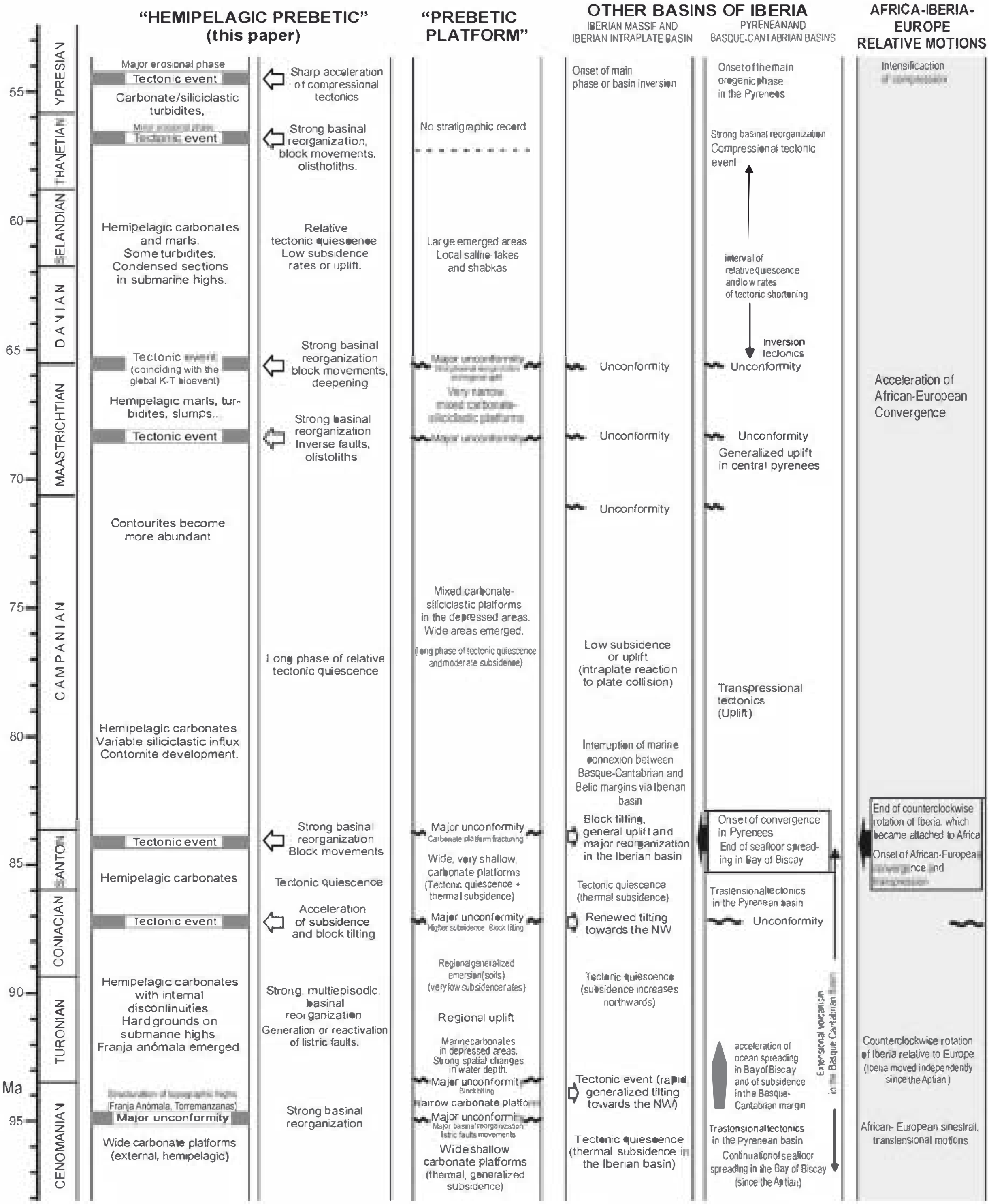

Fig. 10. Summary of the main palaeogeographic changes and evolutionary episodes identified in the study area (Hemipelagic Prebetic) for the late Cretaceous–early Palaeogene interval. Correlation of these episodes with the shallow areas of the same continental margin (Prebetic Platform) and with other basins of Iberia, and integrating the evolution of the continental margin in the geodynamic framework of the relative motions of Africa–Iberia–Europe. Details and references in the text. Time scale after Gradstein et al. (2004).

1991; Gräfe, 1994; Martín-Chivelet, 1996; Gräfe, 1999; Reicherter and Pletsch, 2000; Vilas et al., 2003), characterized by the continuation, or re-establishment, of wide carbonate platforms in shallow basin areas. In the Basque-Cantabrian, Pyrenean and Iberian Basins, major stratigraphic unconformities separate older deposits from the Coniacian–Santonian platforms (e.g., Floquet, 1991; Gräfe, 1994; Gräfe et al., 2002; Berastegui et al., 2002), which could be related to the slowing down of seafloor spreading rates in the Bay of Biscay and transtensional movements occurring between northern Iberia and Europe (Gräfe et al., 2002; Floquet, 2004). It is remarkable that, during this interval of relaxation of intraplate stresses in the southern half of Iberia, the Basque-Cantabrian and Betic margins, became connected via the Iberian intracontinental basin, which acted as a shallow seaway (Alonso et al., 1993).

In the study area, the Coniacian–Santonian interval of relative tectonic quiescence ended around 84 Ma, when the intra-late Santonian event took place. This event, which caused changes in basin geometry, palaeogeography and subsidence patterns, has been described to have had similar consequences in other areas of the continental margin, such as the Prebetic platform (where the event is considered as latest Santonian to earliest Campanian in age, Martín-Chivelet, 1996; Martín-Chivelet et al., 1997; Vilas et al., 2003), and the pelagic domains of the Subbetic (Reicherter and Pletsch, 2000). In general, abrupt block movements and a substantial slowing down of regional subsidence took place. Along with a generalized increase in terrigenous influx and rapid, tectonically induced regression in the Prebetic platform, these factors strongly suggest a compressional origin for the event. This interpretation is in agreement with the changes that were taking place in Iberia and its plate boundaries.

At that time, major plate reorganization occurred between Europe and Africa, causing the end of the counterclockwise rotation of Iberia relative to Europe (Srivastava et al., 1990) and the onset of African–European convergence (e.g., Savostin et al., 1986). Iberia, which had moved independently since the Aptian, then became attached to Africa (Maldonado et al., 1999). All these phenomena induced drastic changes in the basins of Iberia (Fig. 10). In the North, seafloor spreading in the Bay of Biscay finished before chron 34 (latest Santonian, 84 Ma) (Boillot and Malod, 1988; Srivastava et al., 1990; Olivet, 1996). Also, extensional volcanism (which lasted since the Albian) in the Basque-Cantabrian region came to an end (Castañares et al., 2001), and the first thrust-sheets were emplaced in the central-eastern Pyrenees (Puigdefábregas and Souquet, 1986). Moreover, a generalized uplift affected the central part of Iberia, accompanied by major marine regressions (Floquet, 1991; Alonso et al., 1993; García et al., 2004; Floquet, 2004). As a consequence, the marine connection that existed between the Basque-Cantabrian and the Betic margin across the Iberian seaway was definitively cut. In contrast, African–European convergence provoked a stage of penetrative deformation in the Alboran-Kabilias block (cf. Wildi, 1983; Dewey et al., 1989; De Jong, 1990; cf. Puga et al., 2002).

During the Campanian and early Maastrichtian interval, sedimentation took place in the Betic margin in a setting of moderate subsidence, shallower conditions and certain tectonic instability. Block movements and plate adjustments configured a new oceanographic pattern in the hemipelagic settings, allowing the deposition of contourites (bottom-current reworked hemipelagites). The sea floor became affected by deep ocean currents, probably because of its location in the northern boundary of the progressively narrower oceanic passage between Africa and Iberia, through which the equatorial current system flowed in the westernmost area of the Tethys Seaway (Martín-Chivelet et al., 2003).

Sedimentation prevailed until the "mid" Maastrichtian, when the event that occurred around the early to late Maastrichtian transition not only caused major changes in sedimentation but gave rise to the first unequivocal compressional deformations found in the study area. These are reflected in inverse faults and in the coetaneous emplacement of olistoliths. In other areas of the Prebetic as well as in the Subbetic, the event has also been identified. In the former, it marks an abrupt change in the evolution of the shallow platforms (Martín-Chivelet, 1995), whereas in the Subbetic, rapid deepening of pelagic domains took place (Chacón, 2002). There, contourite deposits become replaced by a sedimentation dominated by marls, in which the presence of turbidites and other gravitational deposits is not uncommon. The simultaneous uplift of the shallow areas and sinking of the deeper ones could also be evidence — on a lithospheric scale — of compression, possibly reflecting the vertical lithospheric motions of a basin flank affected by tectonic contraction. Numerical models indicate that when a continental margin is subjected to compression, the peripheral bulge flanking the basin can be magnified, resulting in uplift of the basin flanks and seaward migration of the shoreline (Cloetingh, 1988). Simultaneously, the basin centre deepens, leading to a steeper slope.

The 'mid' Maastrichtian event can be correlated with the major palaeogeographic changes occurring in the northern areas of Iberia, both in the Basque-Cantabrian and the Pyrenean basins (Puigdefábregas and Souquet, 1986; Floquet, 1991; Deramond et al., 1993; Baceta et al., 2004; Floquet, 2004) in response to continued North–South convergence and transpression (Fig. 10). Siliciclastic input notably increased in all basins, probably reflecting the uplift and erosion of central Iberia. Similar compressional episodes have been reported in the Maastrichtian of different locations of northern Africa (e.g., Chotin et al., 2000; Ait Brahim et al., 2002).

The tectonic event in the study area during the Cretaceous–Palaeogene transition caused environmental and palaeogeographical changes related to the global KP mass-extinction. These changes have also been detected in the Prebetic platform, where vertical lithospheric movements, generalized uplift and rapid transgression occurred towards the end of the late Maastrichtian (Martín-Chivelet, 1992). These processes led to the formation of small basins that were lately filled with evaporites (Fourcade, 1970). For the Subbetic, Vera et al. (2003) described a rapid bathymetric change in the pelagic environment, and deposition, during the Danian to earliest Selandian, of massive accumulations of calcarenites bearing *Microcodium* clasts from emerged areas. Throughout the Betic margin, regional tectonism induced rapid differential subsidence. Again, we find shallower areas of uplift and basin centre deepening, probably reflecting the lithospheric motions of a basin flank subjected to compressional episodes (Cloetingh, 1988).

The rest of Iberia and Northern Africa were also characterized by compressional tectonics at this time (e.g., Andeweg, 2002), although most of the studies examining different basins fell short of the temporal or spatial accuracy necessary to establish precise correlations. Across the Pyrenean and Basque-Cantabrian basins, inversion of former Mesozoic normal faults occurred, and subduction or underthrusting was active. Within this compressional setting, however, a period of relative quiescence started around the KP boundary in the Pyrenees, which would last until the end of the Palaeocene or earliest Eocene (e.g., Pujalte et al., 2000; Orue-Etxebarría et al., 2001; Baceta et al., 2004) and which was accompanied by very low rates of tectonic shortening (Vergès and García-Senz, 2001).

The late Thanetian event recognized in the study area represents a regional tectonic pulse that caused erosive phenomena and/or a major changes in sedimentation, defined by the installation of relatively shallow turbiditic systems. De Ruig (1992) also described rapid platform emergence, block-faulting, and tectonic steeping of the continental slope in the margin. All these features strongly suggest a contractional origin for this event. Its correlation with other parts of the continental margin as well as with other basins of Iberia and surrounding areas is, nevertheless difficult, probably because of the lack of accurate studies and precise age-dating. The exception is the Pyrenees (Fig. 10), where Palaeocene–Eocene marine successions are exceptionally developed and exposed. Here, a regional tectonic event marked the end of the period of tectonic quiescence mentioned above. This event, identified by several authors, has been recently dated as latest Thanetian (lower Ilerdian) by Orue-Etxebarría et al. (2001).

Finally, the intra-Ypresian event, which marks the end of the time-span considered in this paper, represented a major event in the evolution of the study area and rest of the Betic margin. This event, which involved deformational structures and a main erosive stage in the Prebetic area (De Ruig, 1992; Geel et al., 1998), marked a sharp acceleration of compressional movements. Major changes in depositional systems and subsidence have also been described in the Subbetic, where the local emplacement of olistostromic units started to take place (Comas, 1978; Vera, 2004). This acceleration in compressional regime has also been reported for the Internal Betics (e.g., Martín-Algarra, 2004), where a phase of high pressure metamorphism started (Puga et al., 2002). Beyond the Betics, the tectonic episode has been described for many places of Iberia and the western Mediterranean area, indicating the broad reorganization of African–European relative motions (e.g., Ziegler, 1988; Dewey et al., 1989). Remarkably, in the Pyrenees, this time coincided with the onset of the main orogenic phase (Puigdefábregas and Souquet, 1986; Vergès and García-Senz, 2001; Muñoz, 2002), and, in the interior of Iberia, the major basin inversions commenced (e.g., Álvaro et al., 1979; Guimerà and Álvaro, 1989; Guimerà et al., 1995; Salas et al., 2001), linked to the transmission of stresses from the northern and southern plate margins.

6. Conclusions and summary

Herein, we examine the upper Cretaceous to lower Eocene hemipelagic successions exposed in the Eastern Prebetic Zone (SE Spain), in an effort to document the development of the ancient southern continental margin of Iberia during its transition from a passive margin to a convergent one. The long-term stratigraphy of these successions is punctuated by six regional events, showing abrupt changes in palaeogeography, environmental conditions and sedimentary facies, as well as significant depositional gaps, variations in sedimentation rates, and enhanced synsedimentary tectonics. Collectively, they suggest important reconfigurations of the basin's architecture that took place at time intervals notably shorter than the chronobiostratigraphy is able to resolve. The ages of these six events, determined by planktonic foraminifera biostratigraphy, are: intra-Coniacian, late Santonian, "mid" Maastrichtian, latest Maastrichtian–earliest Danian, late Thanetian and intra-Ypresian.

The events are tectonic in origin. Each one caused abrupt changes in local and regional subsidence and rapid differential block movements, configuring a new scenario for sedimentation. The sedimentary systems that developed under each scenario are grouped into genetic units bounded by event horizons, herein denoted "event bounded stratigraphic units" (EBSUs). From a regional perspective, by identifying and characterizing these EBSUs, a detailed chronostratigraphic framework can be inferred for the Betic continental margin, from shallow to deep sequences, on which to base further studies.

Through tectonosedimentary characterization of the events and correlations with both, the adjacent shallow marine sequences of the Prebetic platform and the basin pelagites of the Subbetic, each EBSU (but the first) was interpreted as induced by contractional tectonics. Besides, comparisons with other basins of Iberia and Northern Africa allowed us to consider the development of the Betic margin within the framework of the geodynamic evolution of the western Tethys, and to explain the events as the result of changes in intraplate stresses related to relative movements between Africa, Europe and Iberia.

From a methodological standpoint, this work shows the enormous potential of event stratigraphy for analysing large sedimentary basins and making extrabasin correlations.

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